

VECTORS DERIVED FROM BACULOVIRUSES AND USE FOR THE  
TRANSFER OF NUCLEIC ACIDS INTO NERVE CELLS OF  
VERTEBRATES

*175  
A'*

The invention relates to new recombinant  
5 viruses and their use for the transfer of genes into  
the cells of the nervous system of vertebrates. It also  
relates to the pharmaceutical compositions comprising  
said recombinant viruses. More particularly, the  
present invention relates to new factors derived from  
10 baculoviruses and their use for the treatment of  
diseases of the nervous system of vertebrates.

Baculoviruses are circular double-stranded  
DNA-containing enveloped viruses which are specific to  
invertebrates. Their prototype, AcNPV (*autographa*  
15 *californica* multiple nuclear polyhedrosis virus), has a  
genome of 133 kb. This vector is very widely used as  
eukaryotic gene expression vector in insect cells,  
using two strong promoters [polyhedrin (Ph) and P10],  
20 (King and Possee, *The baculovirus expression system*.  
London: Chapman & Hall, 1992.).

Baculovirus stocks may be prepared by  
infecting insect cells (Sf9 or Sf21) with the  
recombinant baculovirus. The production of protein  
occurs by infecting insect cells with the baculovirus:  
25 the cellular medium is harvested and the protein  
synthesized *in vitro* in the insect cells is extracted.

Recombinant baculoviruses are obtained by homologous recombination in insect cells (generally Sf9 or Sf21) between the shuttle plasmid containing the transgene under the control of an active promoter in 5 the cells of vertebrates and the baculovirus genome linearized at the level of the recombination site, or by other techniques well known to persons skilled in the art (transposons, recombination in yeast and the like). Baculoviruses are episomal viruses (in the 10 insect), and make it possible to integrate therein up to 100 kb of recombinant DNA. Thus they have many advantages linked to their ease of production (multiplication in insect cells, industrializable culture conditions, production of high titers), to 15 their large cloning capacity, and to the fact that they exhibit a low risk of dissemination because they are neither replicative in mammals nor disseminative in insects. These vectors have nevertheless not been used in the field of gene therapy because, on the one hand 20 and until very recently, it was accepted that these viruses did not infect mammalian cells, and, on the other hand, the transfection of baculoviruses *in vivo* in mammals has never yet been demonstrated.

Hoffmann et al. (PNAS USA 92 (1995) 10099- 25 10103) have shown that a recombinant baculovirus containing a reporter gene under the control of the CMV early promoter is capable of infecting and of

expressing the transgene in hepatocytes with a very good efficiency: humans (primary culture, Huh7 and HepG2 line) and murines (rabbit primary culture). However, these others did not observe a significant 5 expression of the transgene in a whole series of lines of various origins, including the nervous system (mouse neuroblastoma Neuro-2a, human astrocytoma SW1088 and rat pheochromocytoma PC12).

Boyce F.M. and Bucher N.L.R. PNAS USA 93

10 2348-2352 (1996) have obtained a significant expression of the LacZ gene placed under the control of an RSV promoter in the HepG2 line as well as in the lines 293 (human kidney) A549 (human lung) and PC12 (rat pheochromocytoma). They did not obtain a significant 15 expression in all the other lines tested.

Sandig V. et al. (Human Gene therapy 7 1937-1945 (1996) have used a recombinant baculovirus RSV-LacZ for the infection of human and murine hepatocytes. They have shown that the virus is 20 sensitive to complement and cannot therefore infect the liver *in vivo*. They have nevertheless obtained infection of a piece of human liver infused *ex vivo* with the baculovirus, after removal of the serum.

More recently, Shoji et al. (J. Gen. Virol. 25 1997) have used a recombinant baculovirus containing a reporter gene under the control of the CAG promoter (CMV early enhancer and the chicken  $\beta$ -actin promoter),

and have obtained a significant expression in various cell lines (HepG2, Huh7, CPK, Cos7, Hela, FS-L3 KATO-III). A low expression was detected in the lines RGM-1, PC12, IMR-32 and MT-2.

5 Barsoum et al (Human Gene Therapy, 8 2011-2018 (1997)) have shown that it was possible to modify the viral envelope of a baculovirus containing a  $\beta$ -galactosidase expression cassette under the control of the RSV LTR. This makes it possible to enhance the 10 transduction potential of these vectors, while enhancing the infection of cells infectable with the baculovirus whose envelope is not modified. This also makes it possible to infect cells which were not infectable with the baculovirus whose envelope was not 15 modified. However, the authors did not test the infection of nerve cells. Furthermore, they did not succeed in transducing the Neuro2a (or N2a) cells which are derived from a mouse neuroblastoma.

Thus, up until now, no baculovirus vector has 20 been used for the transfer of genes in vitro or in vivo into the cells of the nerve tissue. Indeed, only the PC12 line, which is capable of exhibiting a "pseudoneuronal" phenotype (rat pheochromocytoma: peripheral nervous system) under specific conditions, 25 has been found to be capable of being infected by the baculovirus; however, the level of expression remained very slightly higher than that of the control. Finally,

no use of the baculovirus for gene transfer *in vivo* in mammals has been described up until now.

The applicant has now shown that it is possible to construct recombinant baculoviruses 5 comprising a heterologous nucleic acid sequence preferably encoding a product of therapeutic interest for the treatment of diseases of the nervous system, to administer these recombinant baculoviruses *in vivo*, and that this administration allows a stable and localized 10 expression of the transgene *in vivo*, and in particular in the nervous system. Indeed, the results presented in the examples demonstrate that the baculoviruses of the invention can infect and direct the expression of transgene in the cells of the nervous system of 15 vertebrates and preferably of humans. By way of illustration of the invention, the examples of the present application surprisingly report the expression of a transgene of interest in at least 60% of differentiated cells of a primary culture of human 20 telencephalon and/or an expression in at least 30% of progenitor telencephalic cells as well as 30% of astrocytes of a primary culture of an adult human cortex. The present invention thus provides viral vectors which can be used directly in gene therapy, 25 which are particularly suitable and effective for directing the expression of transgenes of therapeutic interest *in vivo* in the nervous system or for an

application *ex vivo* for the transfer of genes in cultures of cells of the nervous system and the like (Sertoli cells, muscle cells, and the like) which are intended to be transplanted. The present invention thus 5 offers a particularly advantageous new approach for the treatment and/or prevention of neurodegenerative diseases or for the treatment of metabolic diseases requiring a specific treatment of the nervous system because of the poor accessibility of therapeutic agents 10 which do not cross the blood-brain barrier.

A first subject of the invention consists in recombinant baculoviruses comprising a heterologous nucleic acid sequence encoding a product of therapeutic interest for the treatment of diseases of the nervous 15 system.

In particular, the heterologous nucleic acid sequence may contain one or more therapeutic genes.

The therapeutic genes which can thus be transferred are any gene whose transcription and, 20 possibly, translation in the target cell generate products having a therapeutic effect.

The protein product thus encoded may be a protein or a peptide. This protein product may be homologous with respect to the target cell (that is to 25 say a product which is normally expressed in the target cell when it has no pathological condition). In this case, the expression of a protein makes it possible,

for example, to compensate for an insufficient expression in the cell or the expression of an inactive or weakly active protein because of a modification, or alternatively to overexpress said protein. The 5 therapeutic gene may also encode a mutant of a cellular protein having increased stability, a modified activity, and the like. The protein product may also be heterologous with respect to the target cell. In this case, an expressed protein may, for example, complement 10 or provide an activity which is deficient in the cell, allowing it to combat a pathological condition, or alternatively to inhibit the expression of a protein in the cells, by the use of negative mutants for example.

Among the therapeutic product for the 15 purposes of the present invention, there may be mentioned more particularly hormones, lymphokines: interleukins, interferons, TNF, and the like (FR 9203120), growth factors, enzymes for synthesizing neurotransmitters, trophic factors, in particular 20 neurotrophic factors for the treatment of neurodegenerative diseases, traumas which have damaged the nervous system, or retinal degeneration. For example, members of the neurotrophin family such as NGF, BDNF, NT3, NT4/5, NT6 and their derivatives, 25 members of the CNTF family such as CNTF, axokine, LIF and their derivatives, IL6, cardiotrophin, GDNF and its derivatives, members of the IGF family such as IGF-1

and IGF-2, members of the FGF family such as FGF 1, 2, 3, 4, 5, 6, 7, 8 and 9, and their derivatives, and TGF- $\beta$ .

Among the therapeutic products for the 5 purposes of the present invention, there may also be mentioned tumor suppressor genes: p53, Rb, Rap1A, DCC, k-rev and the like (FR 93 04745), suicide genes: thymidine kinase, cytosine deaminase, and the like.

The nucleic acid sequences encoding products 10 of therapeutic interest for the purposes of the present invention also cover the genes encoding the proteins involved in the metabolism of amino acids, lipids and other constituents of the cell.

There may thus be mentioned, with no 15 limitation being implied, the genes associated with carbohydrate metabolism diseases such as for example fructose-1-phosphate aldolase, fructose-1,6-diphosphatase, glucose-6-phosphatase, lysosomal  $\alpha$ -1,4-glucosidase, amylo-1,6-glucosidase, amylo-(1,4:1,6)-20 transglucosidase, muscular phosphorylase, muscular phosphofructokinase, phosphorylase-b-kinase, galactose-1-phosphate uridyl transferase, all the enzymes of the pyruvate dehydrogenase complex, pyruvate carboxylase, 2-oxoglutarate glyoxylase carboxylase, D-glycerate 25 dehydrogenase.

There may also be mentioned:

- the genes associated with amino acid metabolism diseases such as for example phenylalanine hydroxylase, dihydrobiopterin synthetase, tyrosine aminotransferase, tyrosinase, histidinase,

5 fumarylacetoacetase, glutathione synthetase,  $\gamma$ -glutamylcysteine synthetase, ornithine- $\delta$ -aminotransferase, carbamoylphosphate synthetase, ornithine carbamoyltransferase, argininosuccinate synthetase, argininosuccinate lyase, arginase, L-lysine

10 dehydrogenase, L-lysine ketoglutarate reductase, valine transaminase, leucine isoleucine transaminase, branched chain 2-keto acid decarboxylase, isovaleryl-CoA dehydrogenase, acyl-CoA dehydrogenase, 3-hydroxy-3-methylglutaryl-CoA lyase, acetoacetyl-CoA

15 3-ketothiolase, propionyl-CoA carboxylase, methylmalonyl-CoA mutase, ATP:cobalamin adenosyltransferase, dihydrofolate reductase, methylene tetrahydrofolate reductase, cystathione  $\beta$ -synthetase, sarcosine dehydrogenase complex, proteins belonging to

20 the glycine cleavage system,  $\beta$ -alanine transaminase, serum carnosinase, cerebral homocarnosinase.

- The genes associated with fat and fatty acid metabolism diseases such as, for example, lipoprotein lipase, apolipoprotein C-II, apolipoprotein E, other

25 apolipoproteins, lecithin-cholesterol acyltransferase, LDL receptor, liver sterol hydroxylase, "phytanic acid"  $\alpha$ -hydroxylase.

- The genes associated with lysosomal deficiencies such as, for example, lysosomal  $\alpha$ -L-iduronidase, lysosomal iduronate sulfatase, lysosomal heparan N-sulfatase, lysosomal N-acetyl- $\alpha$ -D-5 glucosaminidase, lysosomal acetyl-CoA: $\alpha$ -glucosamine N-acetyltransferase, lysosomal N-acetyl- $\alpha$ -D-glucosamine 6-sulfatase, lysosomal galactosamine 6-sulfate sulfatase, lysosomal  $\beta$ -galactosidase, lysosomal arylsulfatase B, lysosomal  $\beta$ -glucuronidase, N-10 acetylglucosaminylphosphotransferase, lysosomal  $\alpha$ -D-mannosidase, lysosomal  $\alpha$ -neuraminidase, lysosomal aspartylglycosaminidase, lysosomal  $\alpha$ -L-fucosidase, lysosomal acid lipase, lysosomal acid ceramidase, lysosomal sphingomyelinase, lysosomal 15 glucocerebrosidase and lysosomal galactocerebrosidase, lysosomal galactosylceramidase, lysosomal arylsulfatase A,  $\alpha$ -galactosidase A, lysosomal acid  $\beta$ -galactosidase, lysosomal hexosaminidase A  $\alpha$  chain.

There may also be mentioned, without any 20 restriction, the genes associated with steroid and lipid metabolism diseases, the genes associated with purine and pyrimidine metabolism diseases as well as the genes associated with porphyrin and heme metabolism diseases.

25 The heterologous nucleic acid sequence may be an antisense sequence or gene whose expression in the target cell makes it possible to control the expression

of genes or the transcription of cellular mRNA. Such sequences may for example be transcribed, in the target cell, into RNAs complementary to cellular mRNAs and may thus block their translation into protein, according to 5 the technique described in patent EP 140 308, into autocatalytic RNAs such as ribozymes as well as into RNA modifying splicing in trans.

Generally, the heterologous nucleic acid sequence also comprises a promoter region for 10 transcription which is functional in the infected cell. It may be a promoter region which is naturally responsible for the expression of the gene considered when it is capable of functioning in the infected cell. It may also be regions of a different origin (which are 15 responsible for the expression of other proteins, or which are even synthetic). In particular, it may involve promoter sequences of eukaryotic or viral genes. For example, it may involve promoter sequences derived from the genome of the cell which it is desired 20 to infect. Advantageously, it is a promoter which is active in nerve cells or tissues, especially a eukaryotic promoter. In this regard, it may be for example a ubiquitous promoter, that is to say which is functional in the majority of cell types. Still more 25 preferably, it may therefore be a eukaryotic ubiquitous promoter. The promoter may be autologous, that is to say derived from the same species as the cell in which

the expression is sought, or xenogeneic (obtained from another species). There may be mentioned by way of advantageous examples eukaryotic ubiquitous promoters, strong promoters such as the promoter of the

5 phosphoglycerate kinase 1 (PGK) gene or other promoters directing the expression of the genes for obligatory cellular metabolism (these genes are termed housekeeping genes and specify proteins necessary for functions common to all cells). They are for example

10 genes involved in the Krebs cycle, in cellular respiration or in the replication or transcription or the translation (EF 1- $\alpha$ ). There may be mentioned as specific examples of this type of promoters the promoter of the  $\alpha$ 1-antitrypsin,  $\beta$ -actin, vimentin

15 aldolase A or Efl $\alpha$  (elongation factor) genes.

The promoter used in the context of the invention may also be a eukaryotic promoter specific to nerve cells. There may be mentioned by way of example the promoter of the NSE (Neuron Specific Enolase), NF

20 (Neurofilament), TH (Tyrosine Hydroxylase), DAT (Dopamine Transporter), ChAT (Choline Acetyl Transferase), DBH (Dopamine  $\beta$ -Hydroxylase, TPH (Tryptophan Hydroxylase), GAD (Glutamic Acid Dehydrogenase) and GFAP (Glial Fibrillary Acidic

25 Protein) genes and, more generally, all the promoters of synthesis enzymes or of transporters of neuromediators or any other promoter of genes whose

expression is specific to a given neuronal or glial type or subtype.

It is also possible to envisage the use of viral promoters such as, for example, the CMV 5 (Cytomegalovirus), RSV (Rous Sarcoma Virus), TK (Thymidine Kinase), SV40 (Simian Virus) and RSV, MLV (Murine Leukemia Virus) or HIV (Human Immunodeficiency Virus) LTR (Long Terminal Repeat) promoters.

It is also possible to envisage using 10 chimeric promoters such as CAG (CMV enhancer and chicken  $\beta$ -actin promoter), NRSE-PGK or inducible promoters such as the promoters inducible by tetracycline (Tet-On and Tet-Off), the promoters inducible with ecdysone or alternatively other 15 inducible promoters (RU486, 17 $\beta$ -Estradiol and the like) and in particular promoters inducible by stress, such as heat stress (hsp 70)

In addition, these promoter regions can be modified by addition of activating sequences, 20 regulatory sequences or sequences allowing a tissue-specific or predominant expression.

Moreover, the heterologous nucleic acid sequence may also contain a signal sequence directing the therapeutic product synthesized in the secretory 25 pathways of the target cell or in a specific compartment of the cell. This signal sequence may be the natural signal sequence of the therapeutic product,

but it may also be any other functional signal sequence or an artificial signal sequence.

The virus may be used both in an *ex vivo* and *in vivo* approach. In the context of a gene therapy 5 applicable to humans, it is possible to envisage an *ex vivo* approach by transplanting cells modified genetically by a recombinant baculovirus. These cells may be of various origins: nervous origins (human or non human), Sertoli cells, chromaffine cells and the 10 like. The combination of certain medicaments may be envisaged with a view in particular to improving the retention of the transplant or the expression of the transgene (immunosuppressants, anti-complement and the like). It is also possible to envisage the implantation 15 of cells genetically modified by a recombinant baculovirus after encapsidation in an inert system.

The baculoviruses according to the invention can be prepared by any technique known to the person skilled in the art. In particular, they can be prepared 20 by homologous recombination between a shuttle plasmid and the genome of *Autographa californica* in Sf9 cells and amplified in these same cells according to the method described by Gruenwald S. and Heitz J., 1993 (Baculovirus expression vector system, procedure & 25 method manual. Pharmingen Eds, San Diego, CA). Next, the baculoviruses which have multiplied are recovered

and purified according to conventional molecular biology techniques as illustrated in the examples.

The baculoviruses of the invention cover any derivative of a baculovirus as described and produced 5 above. The expression derivative should be understood to mean any baculovirus having its genome modified either by insertion of sequences into or by deletion of viral genes from the said genome. In particular, the baculovirus derivatives are obtained by deletion of all 10 or part of one or more viral genes. By way of example, there may be mentioned the deletion of the polyhedrin gene, of the P10 gene as well as of any gene which is not essential for the replication of the baculovirus in insect cells in particular. A particular derivative is 15 represented by the deletion of all the baculovirus viral genes (gutless virus) allowing the insertion of a large-size expression cassette.

It is also possible to modify the envelope of the baculoviruses, that is to say to cause an envelope 20 protein other than those of baculoviruses to be expressed at their surface, thus making it possible to modify the host range of the virus. It is thus possible to use envelopes which make it possible to broaden the host range to a very wide variety of cell types or it 25 is possible on the contrary to envisage restricting the host range to a specific type of nerve cell. Among the envelope proteins which can be used, there may be

mentioned in particular: the glycoprotein of VSV, the amphotropic envelope protein of MLV. It is also possible to use envelope proteins which make it possible to specifically enhance the entry of the virus  
5 into neural cells (CNS and/or PNS) such as the rhabdovirus and in particular the rabies virus glycoprotein, the togavirus envelope glycoprotein (alphavirus including Semliki Forest and Sindbis virus, and rubivirus) and in particular the rubella  
10 (rubivirus) envelope glycoprotein, the Herpesvirus (HSV) glycoprotein, or any other neurotropic virus. Preferred variants of recombinant baculoviruses according to the invention are baculoviruses pseudotyped with the glycoprotein of the rabies virus  
15 or the glycoprotein of VSV (Vesicular Stomatitis Virus).

These recombinant vectors can be used for the transfer of nucleic acids into the cells of the nervous tissues *in vitro*, *ex vivo* or *in vivo*.

20 The application *in vivo* may be made especially by stereotaxic injection of the recombinant baculovirus into the central nervous system (brain, medulla) and in particular in the parenchyma or into the spaces containing the cerebrospinal fluid  
25 (intraventricular or intrathecal for example). In this regard, it is possible to use the combination of complement inhibitors (CVF, sCR1 (Hoffman et al., Gene

Therapy, 1998, vol. 5, pp. 531-536), FUT175 and the like) to enhance the transfection efficiency. It is also possible to envisage carrying out the administration of the baculovirus, especially into 5 muscle, so as to reach the nervous system by reverse transport of the baculovirus and/or of the therapeutic product. In the latter case, the injection will be advantageously preceded by inhibition of the complement system *in vivo*.

10 As indicated above, the present invention also relates to any use of a baculovirus as described above for the preparation of a pharmaceutical composition intended for the treatment and/or prevention of diseases of the nervous system. More 15 particularly, it relates to any use of these baculoviruses for the preparation of a pharmaceutical composition intended for the treatment and/or prevention of Parkinson's disease, Alzheimer's disease, amyotrophic lateral sclerosis (ALS), Huntington's 20 disease, epilepsy, multiple sclerosis or other diseases affecting myelinization, as well as diseases affecting metabolism such as lysosomal diseases and in particular the disease MPS VII or Sly syndrome.

The present invention also relates to a 25 pharmaceutical composition comprising one or more recombinant baculoviruses as described above. These pharmaceutical compositions may be formulated for

administration by various routes and in particular by the intramuscular, subcutaneous, intraocular, transdermal, intracerebral, intraventricular or intramedullary route and the like. Preferably, the 5 pharmaceutical compositions of the invention contain a pharmaceutically acceptable vehicle for an injectable formulation, especially for a direct injection into the nervous system of the patient. They may be in particular isotonic sterile solutions or dry, 10 especially freeze-dried, compositions which, upon addition, depending on the case, of sterilized water or physiological saline, allow the constitution of injectable solutions. Direct injection into the nervous system of the patient is advantageous because it makes 15 it possible to concentrate the therapeutic effect at the level of the affected tissues. Direct injection into the central nervous system of the patient is advantageously carried out by means of an apparatus for stereotaxic injection. The use of such an apparatus 20 indeed makes it possible to target the site of injection with great precision.

In this regard, the invention also relates to a method of treating diseases of the nervous system, such as for example neurodegenerative or metabolic 25 diseases, comprising the administration, to a patient, of a recombinant baculovirus as defined above. More particularly, the invention relates to a method of

treating neurodegenerative and/or lysosomal diseases comprising the stereotaxic administration of a recombinant baculovirus as defined above.

The doses of virus used for the injection may 5 be adjusted according to various parameters, and in particular according to the mode of administration used, the relevant pathology, the gene to be expressed or alternatively the desired duration of treatment. In general, the recombinant baculoviruses according to the 10 invention are formulated and administered in the form of doses of between  $10^4$  and  $10^{14}$  pfu/ml, and preferably  $10^6$  to  $10^{10}$  pfu/ml. The term pfu (plaque forming unit) corresponds to the infectivity of a viral solution and is determined by infecting an insect cell culture and 15 measuring, generally after 5 days, the number of plaques of infected cells or else by titration by limiting dilution. The techniques for determining the pfu titer of a viral solution are well documented in the literature.

20 Another subject of the invention relates to any mammalian cell infected by one or more recombinant baculoviruses as described above. More particularly, the invention relates to any human nerve cell population infected by these baculoviruses. This may be 25 in particular glial (astrocyte, microglial, oligodendrocyte, Schwann cell), ependymal or neural cells and the like.

The cells according to the invention may be derived from primary cultures. These may be collected by any technique known to persons skilled in the art and then cultured under conditions allowing their 5 proliferation. As regards more particularly autologous transplants, they may be astrocytic cells, preferably adult human astrocytic cells. As regards heterologous transplants, they may be embryonic cells, preferably human embryonic cells, nerve or neuronal progenitor 10 cells such as the progenitors derived from human telencephalon or mesencephalon which may be possibly differentiated *in vitro* before transplant, embryonic astrocytes; it being possible for these cells to be obtained easily from biopsies. They may also be 15 xenotransplants derived from pheochromocytomas, or embryonic cells or astrocytes or other types of cells such as Sertoli cells. The cells may also be ES cells (Embryonic Stem cells), preferably human ES cells, differentiated in a nervous pathway for example. These 20 cells may be used directly for infection with the baculoviruses or stored, for example by freezing, for the establishment of autologous libraries for a subsequent use. The cells according to the invention may also be secondary cultures obtained for example 25 from preestablished libraries.

The cells in culture are then infected with recombinant baculoviruses so as to confer on them the

capacity to produce a substance of therapeutic interest. The infection is carried out *in vitro* according to techniques known to persons skilled in the art. In particular, according to the type of cells used 5 and the number of copies of virus per cell desired, persons skilled in the art can adjust the multiplicity of infection and optionally the number of cycles of infection performed. It is clearly understood that these steps should be carried out under appropriate 10 sterile conditions when the cells are intended for administration *in vivo*. The doses of recombinant baculovirus used for the infection of the cells may be adjusted by persons skilled in the art according to the desired aim. The conditions described above for the 15 administration *in vivo* can be applied to infection *in vitro*.

Another subject of the invention relates to an implant comprising human cells infected with one or more recombinant baculoviruses as described above, and 20 an extracellular matrix. Preferably, the implants according to the invention comprise  $10^4$  to  $10^{10}$  cells. More preferably, they comprise  $10^6$  to  $10^8$  cells.

More particularly, in the implants of the invention, the extracellular matrix comprises a gelling 25 compound and optionally a support allowing anchorage of the cells.

For the preparation of the implants according to the invention, the various types of gelling agents may be used. The gelling agents are used for the inclusion of the cells in a matrix having the

5 constitution of a gel and to promote anchorage of the cells on the support, where appropriate. Various cell adhesion agents can therefore be used as gelling agents, such as in particular collagen, gelatin, glycosaminoglycans, fibronectin, lectins and the like.

10 Preferably, collagen is used in the context of the present invention. This may be collagen of human, bovine or murine origin. More preferably, type I collagen is used.

As indicated above, the compositions

15 according to the invention advantageously comprise a support allowing anchorage of the cells. The term anchorage designates any form of biological and/or chemical and/or physical interaction bringing about the adhesion and/or attachment of the cells onto the

20 support. Moreover, the cells may either cover the support used, or penetrate inside this support, or both. The use of a nontoxic and/or biocompatible solid support is preferred in the context of the invention. In particular, polytetrafluoroethylene (PTFE) fibers or

25 a support of biological origin may be used.

The implants according to the invention may be implanted at various sites in the body. In

particular, the implantation may be carried out in a muscle, a tumor, the central nervous system or alternatively under a mucous membrane. The implants according to the invention are particularly 5 advantageous in the sense that they make it possible to control the release of the therapeutic product in the body: this is first of all determined by the multiplicity of infection and by the number of implanted cells. Next, the release may be controlled 10 either by withdrawing the implant, which stops the treatment permanently, or by the use of regulatable expression systems which make it possible to induce or to repress the expression of the therapeutic genes.

The present invention thus offers a very 15 effective means for the treatment or prevention of diseases of the nervous system. It is most particularly suitable for the treatment of Alzheimer's disease, Parkinson's disease, Huntington's disease and ALS, or alternatively lysosomal diseases. The baculoviruses 20 according to the present invention have, in addition, considerable advantages linked in particular to their low immunogenicity, because of the lack of expression of the baculovirus proteins in mammalian cells.

The present invention will be described in 25 greater detail with the aid of the following examples which should be considered as illustrative and nonlimiting.

## MATERIALS AND METHODS

**General molecular biology techniques**

5        The methods conventionally used in molecular biology, such as preparative extractions of plasmid DNA, centrifugation of plasmid DNA in cesium chloride gradient, agarose or acrylamide gel electrophoresis, purification of DNA fragments by electroelution,

10      extraction of proteins with phenol or phenol-chloroform, ethanol or isopropanol precipitation of DNA in saline medium, transformation in *Escherichia coli* and the like, are well known to persons skilled in the art and are widely described in the literature

15      [Maniatis T. et al., "Molecular Cloning, a Laboratory Manual", Cold Spring Harbor Laboratory, Cold Spring Harbor, N.Y., 1982; Ausubel F.M. et al. (eds), "Current Protocols in Molecular Biology", John Wiley & Sons, New York, 1987].

20      For the ligations, the DNA fragments can be separated according to their size by agarose or acrylamide gel electrophoresis, extracted with phenol or with phenol/chloroform mixture, precipitated with ethanol and then incubated in the presence of phage T4

25      DNA ligase (Biolabs) according to the recommendations of the supplier.

The filling of the protruding 5' ends can be performed with Klenow fragment of *E. coli* DNA polymerase I (Biolabs) according to the specifications of the supplier. The destruction of the protruding 3' 5 ends is performed in the presence of phage T4 DNA polymerase (Biolabs) used according to the recommendations of the manufacturer. The destruction of the protruding 5' ends is performed by a controlled treatment with S1 nuclease.

10 Site-directed mutagenesis in vitro by synthetic oligodeoxynucleotides can be performed according to the method developed by Taylor et al. [Nucleic Acids Res. 13 (1985) 8749-8764] using the kit distributed by Amersham.

15 The enzymatic amplification of DNA fragments by the so-called PCR technique [Polymerase-catalyzed Chain Reaction, Saiki R.K. et al., Science 230 (1985) 1350-1354; Mullis K.B. and Falloona F.A., Meth. Enzym. 155 (1987) 335-350] can be performed using a DNA 20 thermal cycler (Perkin Elmer Cetus) according to the specifications of the manufacturer.

The verification of the nucleotide sequences can be performed by the method developed by Sanger et al. [Proc. Natl. Acad. Sci. USA, 74 (1977) 5463-5467] 25 using the kit distributed by Amersham.

## LEGEND TO THE FIGURES

5 Figure 1: Percentage of GFP-positive cells preserved in  
the undifferentiated state by addition of bFGF to the  
medium, as a function of the quantity of baculovirus  
Bac-CMV-GFP (1  $\mu$ l corresponding to an MOI of 5).

10 Figure 2: Percentage of GFP-positive cells cultured in  
the presence of 10% of serum (differentiated state), as  
a function of the quantity of baculovirus Bac-CMV-GFP  
(1  $\mu$ l corresponding to an MOI of 5).

15 Figure 3: Comparison and demonstration of the action of  
butyrate in several cell lines: CHP-212, Hela, Cos 7.  
The infection and expression is very significant in  
particular in the CHP-212 cells. The addition of  
butyrate allows expression of GFP in practically 100% of  
these cells.

20 Figure 4: Demonstration of the action of butyrate on  
the infection of progenitor cells cultured in the  
presence of 10% of FCS 48 hours after infection:  
- 4A: action of butyrate expressed as a percentage  
of GFP-positive cells. 48 hours after infection, more  
25 than 60% of the cells express GFP.  
- 4B: action of butyrate expressed as fluorescence  
intensity. 48 hours after infection, the fluorescence

intensity is much higher in the cells subjected to the action of butyrate (intensity of about 425 with butyrate versus an intensity equal to 100 without butyrate).

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Figure 5: Results of the *in vitro* expression of GFP after infection by Bac-CMV-GFP of a culture of human embryonic telencephalic cells:

- 5A: culture of human embryonic telencephalic cells with 10% of FCS. The great majority of these cells are astrocytes.
- 5B: culture of human embryonic telencephalic cells with 10% of FCS and butyrate. All the cells express GFP.

15

Figure 6: Results of the expression of GFP *in vivo* one week after stereotaxic injection in Balb C mice of the baculovirus bac-CMV-GFP:

- 6A: expression of GFP in the striatum.
- 20 Morphologically, the labelled cells appear to be blood vessel epithelial cells as well as a few nerve cells (astrocytes) surrounding the blood vessel.
- 6B: expression of GFP in the striatum. The labelled cells are astrocytes.
- 25 - 6C: expression of GFP in the lateral ventricle. The labelled cells are ependymal cells.

Figure 7: Results in the striatum of the expression of GFP *in vivo* 48 hours after stereotaxic injection in rats, of the baculovirus bac-CMV-GFP. The injection was carried out under the same conditions as described in 5 Example 4 (9  $\mu$ l of virus diluted 1:10). The GFP-expression labelling was carried out by means of an anti-GFP antibody (Clontech).

#### EXAMPLES

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##### **Example 1: Construction of various baculovirus vectors**

1.1 - Construction and production of the Baculovirus RSV-LacZ;

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The recombinant baculovirus RSV-LacZ was obtained by homologous recombination between a shuttle plasmid and the genome of *Autographa californica* in SF9 cells and amplified in these same cells according to 20 the method described by Gruenwald S. and Heitz J., 1993 (Baculovirus expression vector system, procedure & method manual. Pharmingen Eds, San Diego, CA).

The shuttle plasmid was produced by inserting into the plasmid pVL1392 (Pharmingen, San Diego, CA) an 25 expression cassette for the nuclear beta-galactosidase gene under the control of the RSV LTR, and the SV40 polyadenylation signal downstream of the LacZ gene.

This expression cassette was inserted into the multiple cloning site in the reverse orientation in relation to the polyhedrin promoter contained in the plasmid pVL1392.

5                   The virus is then produced by amplification in Sf9 cells. It is concentrated by ultracentrifugation of 180 ml of supernatant (titer initially determined at  $3 \times 10^7$  pfu/ml at 25,000 rpm at 4°C for 90 minutes in an SW 28 rotor and then taken up in 2 ml of PBS and

10                  ultracentrifuged at 25,000 rpm at 4°C for 90 minutes in an SW 41 rotor in a sucrose gradient (10% to 60%, in PBS). The white band corresponding to the purified viral particles is collected and resuspended in PBS and ultracentrifuged at 25,000 rpm at 4°C for 90 minutes.

15                  The pellet is resuspended in 1.5 ml of cold PBS. This concentrated and purified virus stock is stored at 4°C or at -80°C.

1.2 -            Construction and production of the  
20                  baculovirus CAG-LacZ:

The recombinant baculovirus CAG-LacZ was obtained using the shuttle plasmid pAcYM1 (Matsuura et al, J. of Gen. Virol. 68 (1987) 1233-1250). An

25                  expression cassette containing the CAG promoter controlling the expression of the LacZ gene was inserted into the shuttle plasmid. The CAG promoter is

a composite promoter consisting of a CMV IE enhancer, the promoter of chicken *beta*-actin and the polyadenylation signal of rabbit *beta*-globin.

The recombinant baculovirus was obtained by 5 homologous recombination in Sf9 cells and then amplified in these cells (according to the protocol of Matsuura et al., J. of Gen. Virol. 68 (1987) 1233-1250).

The virus used was obtained by amplification 10 of an aliquot of the recombinant baculovirus in Sf9 cells. The titer of the viral solution was determined at  $1 \times 10^9$  pfu/ml. The virus is then concentrated by a factor of 100 and purified under the same conditions as those described for the baculovirus RSV-LacZ.

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### 1.3 Construction and production of the Baculovirus

#### CMV-GFP

The aim of this example is to describe the construction of a recombinant baculovirus carrying a 20 very active expression cassette cloned from the vector pCI vector (Promega) and containing the gene for the Green Fluorescent Protein (EGFP), cloned from the EGFP plasmid (Clontech), under the control of a CMV promoter and a chimeric intron (comprising the 5' splicing site of the  $\beta$ -globin intron and the 3' splicing site of an IgG intron for example) placed upstream of the transgene and an SV40 polyA.

First of all, a shuttle plasmid Bac-CMV containing an expression cassette comprising the CMV early promoter, the SV40 late polyadenylation signal and a multiple cloning site was constructed in order to 5 be able to clone any cDNA for the expression of the latter in mammalian cells. Initially, the cassette was cloned into a vector pVL1392 (Invitrogen), in the reverse orientation to the polyhedrin promoter in order to prevent any transcriptional interference with the 10 baculovirus polyhedrin promoter. The GFP reporter gene was cloned into the shuttle plasmid (Bac-CMV) in order to produce the plasmid Bac-CMV-GFP.

This shuttle plasmid was then transfected into Sf9 insect cells for the production of recombinant 15 baculoviruses, by homologous recombination with the linearized genome of *Autographa californica* (AcNPV). When the virus was amplified on Sf9 insect cells, it was possible for the expression of GFP to be detected by fluorescence microscopy, thus demonstrating that the 20 CMV promoter was active in these cells.

After amplification, the viral stock (Bac. CMV-GFP) was successively concentrated and purified according to the methods previously described. The aliquots were stored at -80°C.

**Example 2: test of infection *in vitro* of various cell cultures by the baculovirus RSV-LacZ**

2.1 - Infection of primary cultures of adult  
5 astrocytes:

The cells are cultured in four-well plates. The infection is made at 37°C in serum-free culture medium for about 2h. It is made with increasing 10 concentrations of recombinant virus. After 24 h, the cells are fixed (4% PFA) and stained with X-Gal. The noninfected controls do not have any blue cell.

Observation of the cultures at 24 and 48 hours after the infection shows that the recombinant 15 baculovirus is capable of infecting cells of a primary culture of human astrocytes (human telencephalon cultured in bFGF) and of expressing the LacZ gene (observed by X-Gal reaction).

20 2.2 - Infection of primary cultures of human  
embryonic telencephalon:

The cells are cultured in a medium containing bFGF (medium which makes it possible to maintain them 25 in a state of undifferentiated or only very slightly differentiated progenitor cells). The infection was

made in complete culture medium for 2h. The noninfected controls have no blue cells.

Observation of the cultures four days after the infection shows that the recombinant baculovirus is 5 capable of infecting human progenitor nerve cells (human telecephalon cultured in bFGF) and of expressing the LacZ gene (observed by X-Gal reaction).

All these results demonstrate that the recombinant vectors derived from baculoviruses are 10 capable of infecting various types of primary cultures of neural cells in vitro and can thus be used as vector for gene therapy for the transfer of genes ex vivo.

**Example 3: test of *in vitro* infection of various cell 15 cultures with the baculovirus Bac-CMV-GFP**

3.1 Infection of various cell lines

In order to assess the efficacy of the vector Bac-CMV-GFP for gene transfer into mammalian cells, the 20 potential activity of this vector to infect and to direct the expression of the GFP reporter gene in various neuronal (CHP212) and nonneuronal (HuH7, 293, HeLa, Cos7) lines was studied. For that, the cell lines HuH7 (human hepatocytes), 293 (human kidneys), HeLa 25 (human epithelium), Cos7 (monkey kidney), N2A (murine neuroblastoma cells) and CHP212 (human neuroblastoma cells) were infected with this vector at an MOI of

12.5. At this vector concentration, the analysis of the fluorescent cells by flow cytometry makes it possible to observe that nearly 100% of the HuH7 and 293 cells are transduced, as well as a high proportion of the 5 CHP212 cells and, to a lesser extent, of the HeLa, Cos7 and N2A cells (of the order of 5 to 20%).

In order to document the phenomena of transcriptional repression of these vectors, the transduced cells were treated with a histone 10 deacetylase inhibitor (butyrate). Indeed, this agent is described as a potent factor capable of lifting the inhibitions of transcription which are due to the condensation of chromatin. Thus, in each case, it was possible to show a significant increase in the number 15 of cells expressing the transgene. Likewise, a high increase in the quantity of fluorescence by cells after induction with butyrate was recorded.

These experiments show the capacity of this vector to effectively transduce a wide range of 20 mammalian cells. Indeed, it was observed that this vector makes it possible to very effectively transduce a human neuronal line (CHP212).

3.2 Infection of primary cultures of nerve cells in vitro

In the same manner as for the cell lines, the vector Bac-CMV-GFP was used to transduce human or 5 rodent primary nerve cells.

Initially, human primary neuroepithelial progenitor cells were infected and cultured in a medium containing bFGF (progenitor state) or cultured in the presence of serum (cells differentiated predominantly 10 in the glial system) with an increasing range of vector up to a quantity corresponding to an MOI of 25. Two days after the infection, analysis by flow cytometry reveals the presence of the order of 30% of progenitor cells-bFGF and of the order of 60% of differentiated 15 progenitor cells, expressing GFP as shown by Figures 1 and 2 respectively. It is of interest to note that the dose/response curve in the case of the progenitor cells did not reach a plateau at an MOI of 25, suggesting that these cells may be infected more substantially.

20 Moreover, double-labelling experiments *in vitro* on human cells of the embryonic telencephalon with the aid of the markers GFAP (astrocyte marker) and MAP 5 (neuron markers) clearly show that these two types of cell are infectable. Indeed, the results 25 provide a GFAP/GFP and MAP5/GFP labelling demonstrating unexpectedly that not only the astrocytes but also the neurons are infected.

In parallel, it was checked on the same cells that the level of "pseudotransduction", that is to say that the number of GFP+ cells which did not synthesize de novo novel [lacuna] of the reporter gene was in all 5 cases less than 3% of the GFP-positive cells. For that, the presence of fluorescence was tested for three hours after the infection, a duration which does not allow effective expression of GFP according to the mechanism of transcription and translation of the GFP gene 10 (Figures 4A and 4B). Furthermore, the inactivation of the viruses by UV irradiation (with a UV-crosslinker at a dose of 100 000  $\mu$ joules approximately) before the infection made it possible to show that there was no longer practically any (less than 3%) GFP-positive 15 cells, therefore confirming the results obtained in pseudotransduction.

The effect of the butyrate was also evaluated on glial cells obtained by differentiation of cultures of human nerve progenitors infected with Bac-CMV-GFP. 20 Twenty-four hours after supplementation of the inducer in the culture medium, a doubling of the number of GFP-positive cells relative to the untreated cells was observed. The mean fluorescence value in the treated cells was however about four times higher than that 25 observed in the untreated cells. These data strongly suggest an epigenetic mechanism of transcriptional repression in the same manner as previously described

for the cell lines. These results show, in addition, that the vector of the invention makes it possible to infect adult human primary astrocytes as well as rat primary pinealocytes.

5 This example therefore demonstrates that a baculovirus containing an expression cassette comprising a promoter (CMV) and a heterologous gene (GFP) is capable of infecting nonneuronal cells but also surprisingly neuronal cells (CHP212 line) as well 10 as nerve cells derived from primary cultures (embryonic or adult) and of directing the expression of the heterologous gene in the said cells at a very significant level.

15 **Example 4: Test in vivo with the baculovirus RSV-LacZ**

4.1 - Stereotaxic injection into rat striatum:

Sprague-Dowley adult female rats were 20 injected with 9  $\mu$ l of concentrated RSV-LacZ virus. The injection was made by slow injection of 1  $\mu$ l of virus (0.25  $\mu$ l/min) at three sites of injection with 3 subsites for each of the sites.

Stereotaxic coordinates relative to the 25 Bregma:

A: +1.8, L: +2.5, V0: -5, V1: -4.6, V2: -4.2

A: +0.6, L: +3.2, V0: -5, V1: -4.6, V2: -4.2

A: +0.6, L: +2, V0: -5, V1: -4.6, V2: -4.2

5 days after infection, the rats are fixed by intracardial infusion of 4% PFA in PBS and the brains post-fixed for 24 h at 4°C in 4% PFA. The brains are 5 then cryoprotected by immersing in 15% sucrose in PBS for 72h. The brains are then frozen in cold isopentane (-50°C) and then preserved at -80°C.

4.2 - Histology on the brains of the rats injected:

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The brains are cut at the level of the striatum with a cryostat (section thickness: 20 µm). The sections are studied by immunohistochemistry in order to detect the presence of *E. coli* β-galactosidase.

15 The slides are washed in PBS, incubated in methanol + 0.3% H2O2 for 1 hour, washed in PBS and then preincubated for 2h with PBS + 10% FCS + 0.1% Triton. Next, they are incubated overnight with the anti-β-Gal antibody (Cappel: 1:5000th), washed with PBS and then 20 incubated with the secondary antibody (Vectastain Goat Anti-Rabbit Kit). The visualization is carried out in DAB + Nickel. Thus, a large number of labelled cells was observed in the two brains (on about 100 sections, making a thickness of about 2 mm around the injection 25 site) .

A double fluorescent labelling β-Gal + GFAP was carried out using an anti-β-Gal monoclonal antibody

(Promega) and an anti-GFAP polyclonal antibody. Very few cells are doubly labelled.

Transduction and a more pronounced labelling of the cells at the periphery of the callous body as 5 well as of the cells in the striatum are observed.

The study, by immunohistochemistry, with the anti- $\beta$ Gal antibody demonstrates that the recombinant baculovirus allows the infection and expression of the transgene in a large number of nerve cells. It also 10 shows that the recombinant baculovirus is not activated by complement in the CNS.

**Example 5: in vivo test with the baculovirus Bac-CMV-GFP**

15 The aim of this example is to demonstrate the capacity of the vector Bac-CMV-GFP to infect nerve cells in vivo.

The vector Bac-CMV-GFP at  $10^6$  pfu was injected into the striatum of adult Sprague Dawley rats and of 20 adult Nude or Balb-C mice. The stereotaxic coordinates for injection are the following:

- For the rats (Sprague Dawley adult female, 200-250 g): injection of 9  $\mu$ l at the rate of 0.25  $\mu$ l per minute in the case of injection of dilute virus, 25 carried out according to the same conditions as in Example 4. An injection of 2  $\mu$ l at the rate of 0.125  $\mu$ l/minute may also be carried out.

Stereotaxic coordinates relative to the Bregma:

A: +1, V: +2.3, L: -5,

- For the mice (Nude or Balb-C adult female, 20-25 g):

5 injection of 2  $\mu$ l at the rate of 0.1  $\mu$ l per minute.

Stereotaxic coordinates relative to the Lambda:

A: +4.7, L: +1.7, V: -3.6,

At two days and one week postinjection, the presence of  
10 striatal cells expressing GFP was detected in the two  
species. In addition to the striatum, other cells  
expressing GFP were also detected in the corpus  
callosum and in the ependyma (Figures 6A, 6B, 6C and  
Figure 7).

15 Immunohistochemical phenotyping makes it  
possible to demonstrate a very high majority of  
GFP/GFAP-positive cells, suggesting a very  
preferentially glial tropism of this vector in the  
brain.

20 These results therefore demonstrate in an  
obvious manner the capacity of the baculovirus to  
infect neural cells *in vivo*.